LCA Methodology with Case Study

Life Cycle Assessment of Frozen Cod Fillets Including Fishery-Specific Environmental Impacts

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Abstract

Goal, Scope and Background. The purpose of the present study was to perform an environmental assessment for the entire life cycle of a seafood product and to include fishery-specific types of environmental impact in inventory and assessment. Environmental data for a frozen block of cod fillets was collected and used for a Life Cycle Assessment, including the fishery-specific environmental aspects seafloor use and biological extraction of target, by-catch and discard species. The fishery takes place in the Baltic Sea where cod is mainly fished by benthic trawls and gillnets.

Methods. The functional unit was a consumer package of frozen cod fillets (400 g) reaching the household. Data was gathered from fishermen, fishery statistics, databases, companies and literature. Fishery-specific issues like the impact on stocks of the target and by-catch species, seafloor impact and discarding were quantified in relation to the functional unit and qualitative impact assessment of these aspects was included.

Results. Findings include the fact that all environmental impact categories assessed (Global Warming Potential, Eutrophication Potential, Acidification Potential, Photochemical Ozone Creation Potential and Aquatic Ecotoxiciy) are dominated by the fishery. Around 700 m^2 of seafloor are swept by trawls and around 50 g of under-sized cod and other marine species are discarded per functional unit. The phases contributing most to total environmental impact following fishery were transports and preparation in the household. The process industry and municipal sewage treatment cause considerable amounts of eutrophying emissions.

Conclusions. Conclusions are that there are considerable options for improvement of the environmental performance of the seafood production chain. In the fishery, the most important environmental measure is to fish sustainably managed stocks. Speed optimisation, increased use of less energy-intensive fishing gear and improved engine and fuel technology are technical measures that would considerably decrease resource use and environmental impact caused by fishery. Due to the importance of fishery for the overall results, the most important environmental improvement option after landing is to maintain high quality and minimise product losses.

Recommendations and Outlook. The need for good baseline data concerning resource use and marine environmental impact of fisheries in order to perform environmental assessment of seafood products was demonstrated. LCA was shown to be a valuable tool for such assessments, which in the future could be used to improve the environmental performance of the seafood production chain or in the development of criteria of eco-labelling of seafood products originating in capture fisheries.

Keywords: Baltic Sea; by-catch; cod; discard; fishery; *Gadus morhua*; gillnet; GIS; LCA; seafloor effects; seafood; trawl

1 Background, Goal and Scope

1.1 Seafood production, today and tomorrow

Seafood is an increasingly important protein source for the growing world population. In developing countries, seafood is often the major source of protein for people. In addition, it is estimated that the percentage of the worlds population living in coastal regions will increase from 65 to 75% within the next 30 years (Anon. 1997), and seafood demand is expected to increase further. The FAO has stated that 2/3 of the worlds major fish stocks, for which assessment data is available, are fully or over-exploited. The production of the worlds capture fisheries seems to have reached its limits and should rather be decreased than increased on a global scale (FAO 2000). Even though aquaculture development has been suggested as a means to meet the growing demand for seafood, the types of aquaculture increasing most rapidly in the developed countries are heavily dependent on wild fisheries for the feed production. Policy-makers, consumers and seafood companies require information about the environmental impact of seafood products today. In this perspective, it is of great importance that methods for assessment of the environmental impact of capture fisheries are developed and that the results from such assessments are used to improve seafood production from an environmental point of view.

1.2 Goal and scope

The present study is a life cycle assessment (LCA) of a consumer-package of frozen cod fillets, originating in the cod fishery in the Baltic Sea. It demonstrates the importance of differ-

ent phases in the life cycle for the different environmental impact categories included, by characterising emissions where recognised methodology is available. Fishery-specific types of environmental impact, such as seafloor effects of towing fishing gear and impact on target, by-catch and discard species of the fishery, introduced in previous publications (Ziegler 2001, Ziegler 2002), were quantified and included in the LCA. Differences between the two most common fishing methods in Swedish cod fisheries in the Baltic, trawling and gillnet fishery, are described. The LCA is, in accordance with the ISO standard (ISO 1997), completed with characterisation of emissions for which recognised characterisation methods are available (see section 2.1) and qualitative impact assessment of environmental impact types that could not be characterised. Aims of the study were:

- To collect inventory data for the entire life cycle of a seafood product, originating in capture fisheries, and characterise emissions when possible
- To include fishery-specific types of environmental impact in the inventory and assessment

2 Methods

2.1 LCA applied to seafood

Biotic resource use and environmental impact of it cannot be measured or calculated in the same, straight-forward way as e.g. the use of fuel or emissions of carbon dioxide. Therefore, resources like land use (Lindeijer et al. 1998) and extraction of biological resources (Sas et al. 1997) are relatively new in LCA methodology and development is still ongoing (Lindeijer et al. 2002). Both of these issues are relevant when studying the environmental impact of seafood production. A system difference when studying fishery compared to other production systems is that the production is wild, i.e. not controlled by man like e.g. in agri and aquaculture, which implies that the sustainability in the use of the resource base should be evaluated when studying the environmental impact of such a system. Characterisation methods are also still under development for ecotoxicological effects. The indexes used in the present study were developed by Heijungs (Heijungs 1992a, Heijungs 1992b). Some researchers work on developing regional impact assessment indexes, which would be very useful, for example eutrophication and toxicity in the marine environment. Current methods are based on data from freshwater ecosystems, which often differ considerably from marine ecosystems in response to nutrient input. Eutrophying emissions were therefore also characterised separately for nitrogen and phosphorous-containing emissions in order to make it possible to evaluate the specific eutrophying potential these emissions have depending on the nutrient status of the recipient (Wenzel et al. 1997). Extraction of natural (fossil fuels and minerals) and biological (landed and discarded catches) resources was not characterised, but the inventory results are listed and seafloor use and impact on target, by-catch and discard species is assessed qualitatively due to lack of data and methodology.

2.2 System boundaries

The 'outer boundary' of the studied system is production of gear, anti-fouling agents, diesel fuel and packaging material, which were all included in the study. Gear material was included as the amounts showed to be significant. Material and energy used for production of the fishing vessel was not included due to earlier findings that these are negligible with regard to the life-time of a fishing vessel (Aanondsen 2001). The product was followed from fishery through a processing plant where it is filleted, frozen and packaged and then transported via a wholesaler and a retailer to the household where it is stored, prepared and consumed. Transportation between the different steps is included, as is wastewater treatment within the industry and waste treatment of the packaging material. The life cycle ends after the municipal sewage treatment plant.

2.3 Functional unit

The functional unit is a consumer package of 400 g of frozen cod fillet reaching the household, fished by Swedish fishermen in the Baltic and processed by a major seafood company. It was chosen because it is an easily understandable unit and a common seafood product in Sweden and is referred to as the product, a cod block or the functional unit (FU). We chose to study the Baltic fishery in general rather than the specific vessels supplying the processing industry with fish, since this makes the results more generally applicable.

2.4 System description

Cod processed to frozen fillets, fished by Swedish fishermen, normally originates in the Baltic Sea, which explains why we used data for Baltic fishery. Three scenarios of it were included; gillnet and trawl fishery and a weighted mixture of the two (47% gillnet and 53% trawl), reflecting the Swedish fishery in the Baltic in 1999. It was then followed through a major processing industry, producing around 30% of the consumer-packed frozen cod fillets consumed in Sweden per year. The industry is situated on the island of Bornholm in Denmark and it processes around 4000 tons of gutted cod per year. Some fish mince is also produced and frozen for transportation to fish finger production, representing 23% of the economic production value. Parts of the cod remaining after filleting are frozen and sold to the pet food industry, as are solids from the industrial wastewater. The consumer-packed cod blocks represent 75% of the product value (i.e. the parts go to pet food production represent 2% of the value). After filleting, freezing and packaging in the industry, the product is transported by truck to the port on Bornholm, Rønne and, from there, by ferry to Ystad in Sweden. From Ystad, the cod blocks are taken by lorry to storage in Helsingborg from where they are transported to all major wholesalers in Sweden. The product is stored at the wholesaler and then transported to retail stores all over the country. From the retail store, the product is generally transported by car or bicycle to the household (Orremo et al. 1999), where the consumer normally stores it in the freezer before preparation. It was assumed that the fish is prepared in the oven and that the household wastewater is connected to municipal sewage treatment. It has also been assumed that no product waste occurs after the processing industry. For a more detailed system description, data and assumptions, see a data report from the project (Ziegler 2002).

2.5 Inventory methodology

2.5.1 Target, by-catch and discard species

In the demersal fisheries of the Baltic Sea, cod (*Gadus morhua*) is the main target species. Some by-catches are landed, but they represent a low percentage in weight (<1.5%) and even less economic value compared to cod (<1%). The impact on the

target species of the Swedish cod fishery in the Baltic was evaluated, using stock assessment data for 1999 concerning the estimated total biomass, spawning biomass, recruitment and mortality (Sjöstrand 1999, Sjöstrand 2001). Data on Swedish cod landings and by-catches by different gears for 1999 was also obtained from the fishery statistics at the NBF.

Landing and discard data for cod fishery in the Baltic Sea was obtained from the International Baltic Sea Sampling Program (IBSSP), sampling commercial fishing vessels randomly (Walther 2001). Samples from different Baltic areas and different months of 1999 were given aggregated as biomass of cod for the two gears; gillnets and trawls. For economical allocation, average first-hand prices for 1999 were used (SFPO 2000).

2.5.2 Seafloor effects

The total seafloor area swept by trawls was quantified by multiplying trawl dimensions and typical speeds, provided by trawling fishermen and a trawl manufacturer (Edvardsson 2000), and by the reported fishing effort in the Baltic during 1999 with those gears. This calculation led to a rough estimate of the number of square metres of seafloor impacted per kg of cod landed. However, the impact is not evenly distributed over the seafloor and the long-term impact is dependent on the intensity in trawling (Lindeboom and de Groot 1998). Moreover, as the type and sensitivity of the seafloor differs between different areas, we wanted to know what type of seafloor is really impacted and how often. Therefore, a depth below which oxygen-depletion is common was determined by comparing depth profiles of the Baltic Sea and maps of oxygen content at different depths (SMF 2001). The depth isocline for 80m, corresponding to the depth of the Baltic halocline (salinity stratification), was therefore overlayed with fishing effort data from the Swedish fisheries statistics in a Geographical Information System (GIS) software (ESRI 2000). This analysis gave information about the proportion of trawl effort taking place in areas where seafloor sediments are more regularly oxygen-depleted and a value of impacted seafloor above and below 80 m in relation to the catches was obtained. Gillnet fishery has been considered not to affect the seafloor.

2.5.3 Anti-fouling paints

The use of anti-fouling agents in the Swedish cod fishery was calculated roughly from a questionnaire sent to fishermen and reported previously (Ziegler and Hansson, in press). The result from the around 30 fishermen who responded to the questionnaire was that around 0.5ml of paint per kg of cod landed is used. There was no general difference between trawlers and gillnet fishing vessels regarding use of anti-fouling agents. A type of paint in the midrange of the paints in use concerning content of CuO was used for the calculations of copper emissions. Data on the energy consumption and emissions during production of anti-fouling paints was obtained from the manufacturer, Jotun A/S, and their production plant in the United Kingdom.

2.5.4 Ice and fishing gear material

Ice is used to maintain the quality of fish before landing. In general, gillnet vessels take ice with them from land, while trawlers have an ice machine installed on board and have a cool storage room for the catch. While the vessel is in the harbour, the room is cooled by electricity while at sea it is run by the diesel engine. Gillnet fishing vessels take the ice from a machine on land of a similar size as the one many trawlers have onboard, either owned by themselves or together with other fishermen. The energy for the ice production is, in this case, not included in the overall diesel fuel consumption, which explains some of the difference in fuel consumption between the two fishing methods. See Ziegler (2002) for more details on data and calculations.

For the calculation of material used in the production of fishing gear, fishermen and gear manufacturers provided us with data on material content and life-time of the gears. Data and assumptions were reported in Ziegler (2002).

2.5.6 Emissions from fuel combustion

Fuel consumption and emission data from a previous investigation (Ziegler and Hansson, in press) were gathered and calculated on the basis of the same functional unit as in the present study and the data from that study could therefore be used to obtain allocated emission data for the Baltic cod fishery. Data used for the present study are shown in **Table 1**.

2.5.7 The life cycle after fishery

Data for production, resource use and emissions from the processing industry was obtained for the year 2000 (Hansson 2001). In the processing industry, several products are produced, but cod blocks are dominating both in quantity and in gross sales value and the other products can be regarded as by-products, which would not be produced if the main product would not be frozen cod fillets. For these reasons, economical allocation was performed in the processing industry. The industrial wastewater is treated in a plant owned by three seafood processing industries together and a mass allocation was performed to calculate how much of the nutrient emissions are due to the studied production (Jørgensen 2001), assuming the wastewater from the three seafood companies has a similar nutrient content.

Data on energy use and quality of the primary packaging (LDPE-laminated cardboard) of the product was taken from the cardboard producer (Anon. 2001) and from a database (CIT-

Table 1: Emissions from Swedish cod fishery in the Baltic (economical allocation performed for by-catches) during 1999

	Emissions (g/kg cod landed)				
Fishing gear	HC	NO_x	CO	SO_x	CO_2
Trawling	2.69	87.4	4.56	0.83	3782
Gillnet fishing	1.04	18.4	1.48	0.20	912
Weighted total[a]	1.92	55.0	3.11	0.53	2433

[a] 47% fished by gillnets and 53% trawled

Ekologik 2001c). LDPE is also the only secondary packaging material. Environmental data for waste treatment by landfill and incineration were taken from a report (Sundqvist 1999). Transport of frozen products requires around 11% more fuel than truck transports without cooling or freezing, and the product is stored for around one month in Helsingborg (Thelin 2001). The main wholesalers of the processing industry, as well as road carriers gave information about turnover time, transport distances and energy consumption in the later phases of the life cycle. For more details, see Ziegler (2002).

A study on LCA data for retail stores was used (Carlson and Sonesson 2000) and combined with specific energy consumption data from manufacturers of retail freezes (Rindhagen 2001). For transportation from the retailer to the household, the average distance is 7.8 km (Orremo 1999) and the fuel consumption of a car was assumed to be 0.08 L/km. Economical allocation was performed for this transport based on the product price and an average sum spent per shopping occasion (Orremo et al. 1999).

Data and volume allocation method for storage at home was obtained from a methodology developed for food product LCAs (Stadig 2001) and energy data for preparation of a cod block from measurements in a test kitchen (Thorsell Nilsson 2000). Resource use and emission data for truck transports as well as production of fuel and energy was taken from a database (CIT-Ekologik 2001a). The product content of nutrients was determined from two publications about nutrient content of fish and food in general (Hjerne and Hansson 2001 and Anon. 1986). Standard values on the efficiency of municipal sewage treatment were used (SEPA 1997). The energy consumption for modern sewage treatment was obtained from a study (Dalemo 1996). The LCA was performed in the software LCAiT (CIT-Ekologik 2001b). The following environmental impact categories were included:

- Global Warming Potential (100 years), as g CO_2 equivalents per FU;
- Acidification (max), as g SO_2 equivalents per FU;
- Eutrophication (EPD), as g O_2 equivalents per FU;
- Eutrophication (N), as nitrogen equivalents per FU;
- Eutrophication (P), as phosphorous equivalents per FU;
- Aquatic Ecotoxicity, as 1000 m^3 polluted water per FU; Photo-chemical Ozone Creation Potential, as g ethene equivalents per FU.

Impact assessment indexes were taken from a database (CIT-Ekologik 2000), except Eutrophication N and P (Wenzel 1997), Aquatic Ecotoxicity (Heijungs 1992a, Heijungs 1992b) and Eutrophication Potential (EPD) (Anon. 1999). Resource use and other environmental impacts that could not be characterised are presented and discussed as to quantity and quality.

3 Results

3.1 The entire life-cycle

Fishery is the phase of the life cycle dominating all investigated impact categories, except for Eutrophication (P), in which the process industry is the main contributor to phosphorous-containing emissions. Fishery includes gear, anti-fouling, ice and diesel production, but all these activities are all negligible compared to the fuel consumption in fishery which was assumed to be a mix between gillnet and trawl fishery reflecting the Swedish fishery in the Baltic in 1999. For the impact categories dominated by fishery (i.e. all except EPP), fishing is most dominant in Aquatic Ecotoxicity (99.7%) and least dominant in Eutrophication Potential (70.1%) (**Fig. 1**)

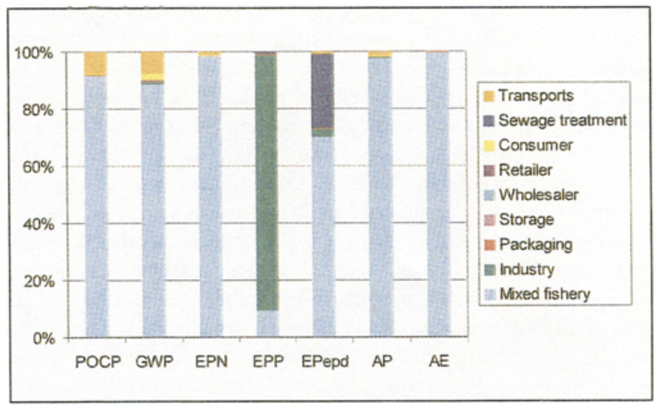

Fig. 1: Contribution of the different phases of the life cycle of the product to environmental impact categories (POCP: Photochemical Ozone Creation Potential, GWP: Global Warming Potential, EPN: Nitrogen Eutrophication Potential, EPP: Phosphorous Eutrophication Potential, EPepd: Eutrophication Potential, AP: Acidification Potential, AE: Aquatic Ecotoxicity)

3.1.1 Global warming potential (100 years)

Mixed cod fishery is responsible for 89% of the emitted CO_2-equivalents. The main part of this is due to fuel consumption on the fishing vessel and the most important contributors to GWP are carbon dioxide, nitrogen oxide and methane emissions. The three fishery scenarios; pure gillnet, pure trawling and combined gillnet and trawl fisheries (**Fig. 2**), demonstrate a considerable

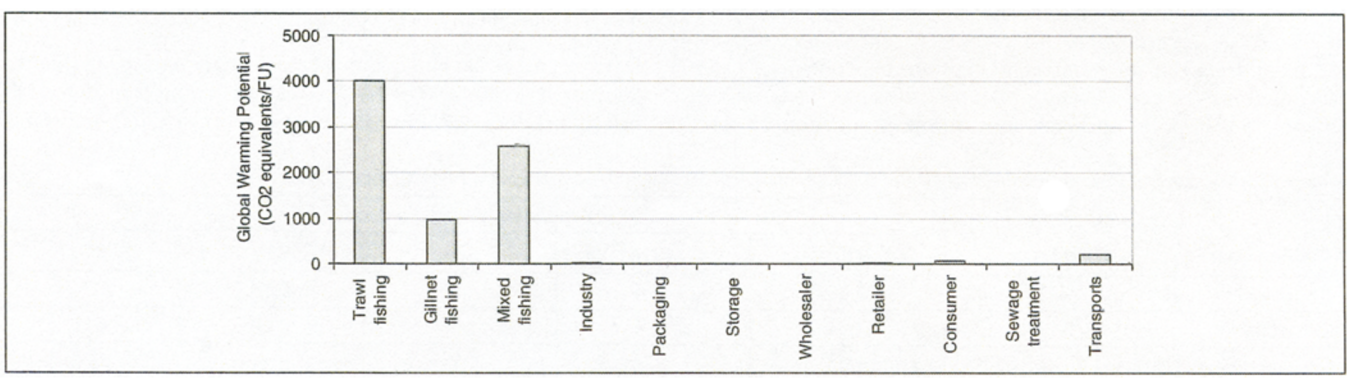

Fig. 2: Distribution of Global Warming Potential between different life cycle phases with three alternative scenarios for fishery: a) 100% trawl fishing, b) 100% gillnet fishing and c) 47% gillnet and 53% trawl fishing

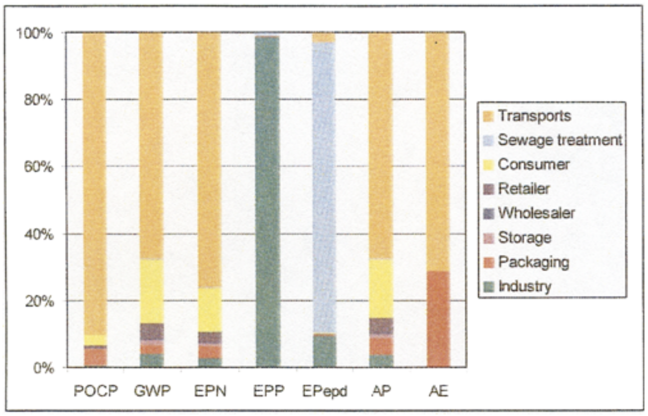

Fig. 3: Contribution of the different phases of the life cycle to environmental impact categories when fishery is excluded (POCP: Photochemical Ozone Creation Potential, GWP: Global Warming Potential, EPN: Nitrogen Eutrophication Potential, EPP: Phosphorous Eutrophication Potential, EPepd: Eutrophication Potential, AP: Acidification Potential, AE: Aquatic Ecotoxicity)

difference between the fishing methods, mainly due to the difference in fuel consumption onboard. When fishery is excluded, transports and consumer are the most important phases for global warming (**Fig. 3**, GWP). The dominating transport is the home transport from the retailer to the household and the activity dominating in the consumer phase is the preparation of food rather than storage. The transports summed are only the product transports, by truck, ferry and car; not transports of supply materials, which are included under each phase, e.g. fishery and packaging, but these are negligible compared to the product transports.

3.1.2 Acidification potential

Acidification is likewise dominated by fishery (**Fig. 4**), followed by transports (Fig. 3, AP). The main contributors to acidification are nitrogen oxides and sulphur oxides, which can be seen in Fig. 4 where a scenario is included, assuming a modern fuel (97% lower sulphur content) is used. The decrease in acidification potential due to the change of fuel would be small, because nitrogen oxides are so dominating.

3.1.3 Eutrophication potential

For eutrophication (EPepd), the pattern looks somewhat different. Fishery is also dominating due to emissions of nitrogen oxides to air (Fig. 1, EPepd), followed by sewage treatment with emissions of nitrogen and phosphorous to water (Figs. 1 and 3). When split up on nitrogen and phosphorous (EPN and EPP), however, the process industry is responsible for most of the phosphorous-containing emissions (Fig. 1, EPP).

3.1.4 Photochemical ozone creation potential

The main contributors to POCP are volatile organic compounds (VOCs), hydrocarbon and carbon monoxide emissions. The former two result from diesel and gasoline combustion and the latter is also formed during electricity production (Figs. 1 and 3, POCP).

3.1.5 Aquatic ecotoxicity

Aquatic Ecotoxicity is completely dominated by the intentional use of copper as an anti-fouling agent and it overshadows toxic substances released in diesel and gasoline production and combustion which rate transports the second most important source of ecotoxic substances (the dominance of fishery and transports can be seen in Figs. 1 and 3, AE).

3.1.6 Primary resources and secondary energy

Primary resources used during the life-cycle of the product are shown in **Table 2**. Resource use can be expected to be underestimated, since minor flows were not always followed back to

Table 2: The main primary resources used for production of a cod block (mixed fisheries), unit: g/FU, except seafloor: m^2/FU

Primary resources	Resource	Amount
Energy-containing	Crude oil	740
	Coal	32
	Natural gas	38
	Uranium in ore	0.03
Other	Bauxit	0.003
	Copper	0.13
	Iron	0.34
	Lead	2.1
	Commercial cod	1000
	Discarded biomass	50
	Seafloor (m^2)	700

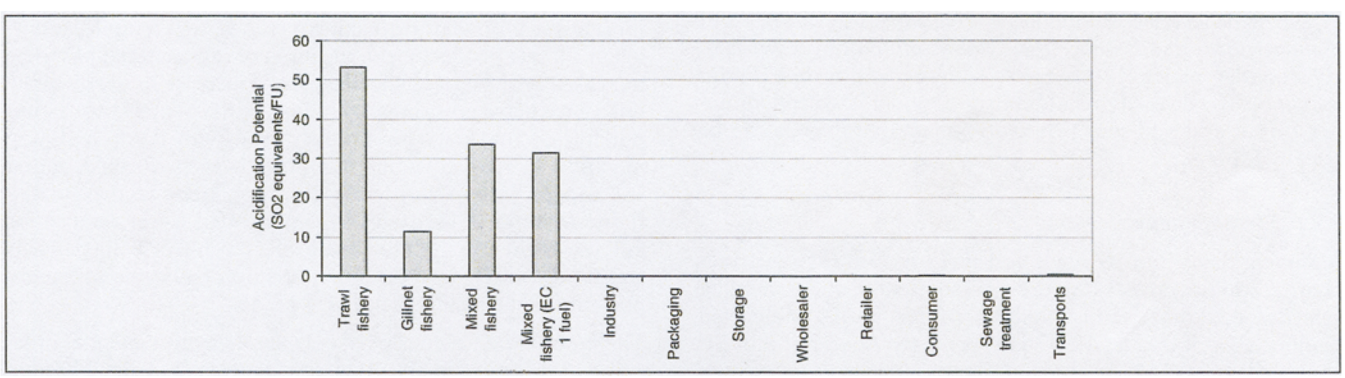

Fig. 4: Acidification Potential including the three fishery scenarios a) 100% trawl fishing, b) 100% gillnet fishing, c) 47% gillnet and 53% trawl fishing and d) a scenario where a fuel with lower sulphur content is used (EC 1)

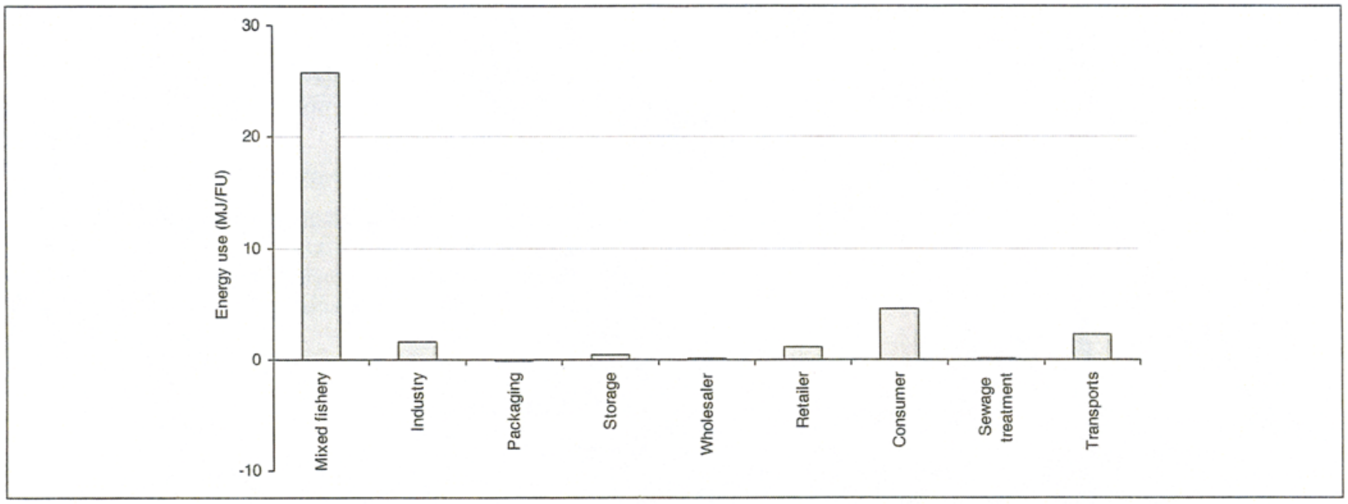

Fig. 5: Use of secondary energy in each life cycle phase of the studied product

primary resources. Energy use in the different life-cycle phases is shown in **Fig.** 5. Fishery represents 72% of the total energy used during the life cycle of a cod block when it is mixed like the Swedish fisheries in the Baltic were in 1999 (Fig. 5). The total figure for energy consumption (36 MJ/FU or 90 MJ/kg of frozen cod fillet) is the sum of all energy-containing inputs to the life-cycle phases resulting after calculating the Life Cycle Inventory results.

3.2 Fishery-specific issues

3.2.1 Target species, by-catch and discard

Total international landings of cod from the Baltic were around 115,000 tons in 1999. The greatest part was caught from the eastern stock (63%). Around 60% of the estimated total biomass of the eastern stock was fished in that year. Excluding the youngest year classes, the ratio between landings and spawning biomass was 0.98. Recruitment has been low and fishing mortality high during a number of years and today the stock is considered to be in a critical condition. The western stock is also considered to be fished outside safe biological limits, here the removal of biomass was 70% and the ratio between landings and spawning biomass is over one, indicating that large amounts of smaller fish were taken (Sjöstrand 1999, Sjöstrand 2001). To conclude, these figures indicate that Baltic cod is a resource that is currently not used on a sustainable basis.

Landed by-catch was around 7 kg/ton cod landed for gillnet fisheries and 12 kg/ton cod landed for trawl fisheries (0.3 and 1.1% of economic value) during 1999. Main by-catch species in gillnet fishery were flounder (*Platichthys flesus*), sea trout (*Salmo trutta*) and vendace (*Coregonus albula*); in trawl fishery flounder, plaice (*Pleuronectes platessa*) and turbot (*Psetta maxima*). The discards mainly consist of under-sized cod, flounder, turbot and bull-rout (*Myoxocephalus scorpius*) as can be seen in **Table** 3.

Table 3: Main discard species (kg/ton cod landed per ton cod landed, 1999)

Species	Trawl	Gillnet
Flounder	26	22
Cod	49	18
Turbot	2.5	0.1
Bull-rout	0	6.6

3.2.2 Seafloor impact

Assuming that a typical single cod trawl is 55m between otter boards, double trawls 110m (Edvardsson 2000), and a trawling velocity of 2 knots (nautical miles per hour) gives an impacted seafloor area of 0.22 and 0.43 km^2 per trawl hour, respectively. Multiplying trawl effort data with these factors gave an average value of 1711 m^2 of impacted seafloor per kg of trawled cod, corresponding to a square of 42 x 42 m. Dividing the fishing effort into above and below the 80 m-depth-isocline and overlaying the fishery statistics data with the 80m-isocline in the GIS showed that 93% of the trawl effort occurs in sediments shallower than 80 m, i.e. in areas with a benthic community, while 7% of the effort occurs in sediments deeper than 80 m, i.e. in areas that are colonised mainly by sulphur and nitrogen-reducing bacteria. Weighting of the total seafloor impact value by catches shows that 1,593 m^2 of seafloor above 80 m and 119 m^2 below 80 m are impacted per kg of trawled cod. Weighting according to the distribution between gillnet and trawl fisheries in the Baltic today and relating it to the FU gave a total impacted area of 706 m^2/FU (657 m^2 above 80 m and 49 m^2 below).

4 Discussion and Conclusions

4.1 The importance of fishery

The importance of fishery and the fishing method was clearly demonstrated. Less evident was whether the resulting product quality when fishing with the two methods is identical. If quality is lower for one of the fishing methods, for example, resulting in a lower product yield, the input of raw material has to be increased proportionally, which would increase or decrease the difference between fishing methods. Unfortunately, it was not possible to find data for product yield with the two fishing methods. In Norway some tests have been performed, rating fish caught with two different gears according to the Quality Index Method (QIM) which demonstrated lower quality for gillnet-caught fish than for line-fished catch (Akse 2001). This subject definitely deserves more attention and can be very important for the results of seafood LCAs.

The studied product consists of only one ingredient and is not prepared or preserved in any other way than being frozen. For food products that are processed or transported more, those life-cycle phases are more important (Andersson 2000). A screening LCA for

pickled herring showed, for example, that the most important activities in the life cycle of a jar of pickled herring was fishery, the canning industry and the consumer phase (Ritter 1997). It also demonstrated a difference between trawl and seine fisheries with trawling requiring around 50% more energy than seining (a passive fishing method with a trawl-shaped net). However, we cannot draw general conclusions about the environmental performance of fishing gear. In a previous study (Ziegler and Hansson, in press), it was concluded that the energy-efficiency of fishing gears can differ between fisheries, depending on the catches obtained and the allocation method used to allocate between them. A study of the Finnish herring fishery in the northern part of the Baltic Sea (Lillsunde 2001) showed higher fuel consumption for gillnetting, when pelagic herring trawling was compared to coastal gillnet fishing.

4.2 Effects on the Baltic cod stocks

For the year 2000, it has been estimated that 80% of the Baltic cod landings came from the year classes '97 and '98 (Walther 2001). Baltic cod normally matures at an age of three years while the Atlantic cod matures at six to nine years (Curry-Lindahl 1985, Vallin 1999). This means that a high percentage of the catches have not been able to reproduce before being caught. Size distribution of fish populations is important as reproduction is more successful for repeat-spawners than for first-time spawners (Vallin 1999). Therefore, it is of great importance that more large specimens survive to reproduce and ensure a recovery of the stocks and that juvenile individuals are left to reproduce at least once before being fished. It has to be concluded from these data that the fishery for cod in the Baltic, at present, is not performed on a sustainable level and that strong measures are necessary to turn the negative trend of the two Baltic cod stocks.

Discarding does not add any new nutrients to the ecosystem, but it transforms nutrients from the top of the foodweb to bioavailable forms of nutrients, which increases the nutrient turnover time and biological production. However, in relation to the anthropological nutrient input and the massive removal of nutrients by the fishery (Hjerne and Hansson 2001), the amounts of nutrients resulting from discarding are small.

The discard figures in Table 3 are low compared to many other fisheries in the world (Alverson et al. 1994). This is due both to the low biodiversity in the Baltic and to the gear types used. The discards mainly consist of under-sized specimens of commercial species like cod. A calculation was made to estimate the effect of avoiding to catch under-sized cod in the Baltic, i.e. that all cod discarded today would survive, continue growing and reach maturity before being fished (Sjöstrand 2001). With an estimated natural mortality of 20% and the present fishing pattern, not discarding would lead to an increase in catches corresponding to the total Swedish landings of cod today. These calculations showed that in Swedish trawl fishery today, 71 kg of 'future cod catches' and 69 kg of 'future spawning biomass' are discarded along with every ton of cod landed. In gillnet fishery the corresponding figures are 26 kg of future cod catches and 25 kg of future spawning biomass. Discarding under-sized cod is therefore both a biological and economic waste of a limited resource.

4.3 Effects on the Baltic seafloor

It must be kept in mind that the seafloor impact calculated here is only for the Swedish fishery, which represents 15–20% of total cod fishery in the Baltic (in catches). The area swept by trawls is not evenly impacted and seafloor effects will be depending on the type of habitat impacted and the frequency of this disturbance. At this point, data to analyse this in detail for the Baltic Sea is not available, why we only can discuss results in relation to findings from other areas. In a study from the Kiel Bight in Germany, the chemical effects of trawling were assessed (Krost 1993). Trawling in the bights' oozy sediments caused complete liberation of nutrients and hydrogen sulphide dissolved in the sediment pore water and the otter boards of the trawl left tracks that remained visible for several years. The total amount of nutrients released into the bight due to trawl fishery was only a small percentage of the total annual input, but since hydrogen sulphide requires oxygen for decomposition, it was concluded that bottom trawling can contribute to oxygen depletion and should be suspended during low-oxygen periods. These findings are highly relevant for the Baltic Sea, because of its natural low-oxygen conditions in deeper layers and important since the availability of oxygen-rich and high-saline deep water is a limiting factor for the reproduction of cod and thus for the recovery of the stocks.

Clearly, there will also be biological effects on marine communities in the sediments that are trawled. Studies from true marine areas have shown large-scale effects of trawling with increased abundance of short-lived scavenger species and a decrease in filter-feeding species, especially fragile ones with long turnover times, like corals living on the seabed surface (Olsson and Nellbring 1996, Hall 1999, Anon. 2000). However, in benthic communities in the Baltic, diversity is low even before any kind of human-caused impact has occurred. The species living there had to be stress-tolerant to be able to colonise the brackish water environment in the first way. Due to the special conditions in the Baltic Sea, communities are sensitive to additional stress, e.g. caused by eutrophication or fishery by towing gear, and any impact on the structure of the benthic community will reduce complexity further. However, more detailed data on habitat distribution and experimental studies studying fishery effects on the seafloor are needed in order to quantify the biological effects of trawling in a specific area.

4.4 Environmental risks in fishery

Even though loss of gear is rare, accidents happen and lost gear can pose both a biological and a chemical risk. Gillnets contain lead which in case of loss will remain on the seafloor for a long time, creating a potential environmental risk. Both lost gillnets and trawls can maintain a high fishing capacity and continue to 'ghost-fish' for a long time. Due to the lack of data on these issues, they were not included in the assessment.

Sometimes, solid waste is thrown overboard from fishing vessels, especially when vessels are out on longer fishing trips (Luetzen 1996). Fishing trips in the studied fisheries are generally short and all fishermen said that they bring their waste ashore, so that normally no disposal of solid waste occurs.

The risk of accidental oil spills or spills of anti-fouling substances and other chemicals in fishery is considered to be low.

4.5 Allocation methodology

An overview over the allocations done in this study is given in Table 4. It has been shown previously that allocation methodol-

Table 4: Summary of all allocations made in the LCA

Life-cycle phase	Type of allocation	Allocation to main product
Fishery	Economic	99%
Process industry	Economic	75%
Home transport	Economic	17%
Household storage	Product volume	0.34%

ogy can be very important in mixed fisheries, but that it does not significantly impact the results in the Baltic cod fishery where the by-catches are low and have low economic value (Ziegler and Hansson, in press). In the industry phase, however, an allocation based on mass, for example, would give a completely different, and less relevant, result. The parts of the cod which end up in the pet food industry represent a significant part of the mass flow, over 50%, but have a low economic value for the company (2%). For the transport home from the retailer, the economic allocation is the reason why it is so significant. Mass or volume allocation would give less importance to the product. However, we believe that economical allocation is the best alternative after system expansion, reflecting the cause of the car transport. System expansion was not considered to be a feasible option in this case. It is remarkable that the home transport gives such a high contribution even though it was assumed that 41% of the purchases are not transported by car (i.e. by bicycle or walking). It can be argued that the purchase of food is not the only cause of the car trip, but Orremo et al. (1999) state that this is actually the common case. In the household phase, for storage in the freezer, allocation was made on the basis of product volume and storage time, which is believed to best reflect the energy consumption caused by the product in this phase.

4.6 Impact assessment methodology

The application of characterisation methods for eutrophying emissions to the marine environment, e.g. Eutrophication Potential (EPD) (Anon. 1999), can be subject for discussion. These methods were developed to be applicable in all kinds of environments, but the impact of phosphate emissions is very different, e.g. in lakes and in the sea. Phosphorous has much higher impact index than nitrogen (e.g. phosphate: 46, ammonia: 15 and nitrate: 6 g O_2 equivalents/g emitted, respectively) in this method, as well as in other characterisation methods. This might be a valid estimate in a phosphorous-limited environment, but in many oceans, including the main part of the Baltic Proper (Kautsky and Kautsky 2000), the growth-limiting nutrient is nitrogen rather than phosphorous and hence, emissions of nitrogen compounds will have larger eutrophying potentials in that environment. Therefore, the specific eutrophication potentials for nitrogen and phosphorous were calculated (Wenzel et al. 1997). It can also be discussed whether the emission of nutrients from a sewage treatment plant, coming from the seafood itself, really are emissions. We followed the recommendation that the system boundary of an LCA should lay where the limit between the natural and the technical system is (ISO 1997), in this case starting with fishery and ending with sewage treatment. Sewage water is generally discharged in coastal areas, where water exchange is limited, and the eutrophying potential is higher than at open sea, a reason why its inclusion might be motivated. The application of copper-containing paints was the main cause of toxic emissions in the lifecycle of the studied product, followed by transports. However, the methodology for characterisation of toxic substances (Heijungs 1992a, Heijungs 1992b) is not complete and dioxins, for instance, are, at present, not characterised, a reason why the dominance of copper in the results might be somewhat overestimated. The main part of the emissions of acidifying compounds at high sea will probably be deposited in the oceans. These emissions do not cause acidification, since the oceans constitute a giant carbonate-buffered solution. The development of geographical or environment-specific characterisation factors is necessary to achieve a more realistic picture of the environmental impact in marine environments.

4.7 Data uncertainty

The most important data used in this LCA are the fuel consumption and resulting emissions in the fishery, gasoline consumption in the transport from the retailer to the household, electricity use for preparation of the food at home, nutrient emissions from the sewage treatment plant as well as emissions of copper from anti-fouling paints. The data material on fuel consumption in fishery is limited and therefore subject to uncertainty. However, as stated in Ziegler and Hansson (in press), the values are relatively similar to those reported for cod fisheries in other countries and the variation in fuel consumption within gear types was limited. For the gasoline use, distance and allocation method for the home transport, literature data was used, which must be considered being the most representative data for Swedish conditions (Orremo et al. 1999). Electricity used for preparation of cod in the oven was measured and an average value was used (Thorsell Nilsson 2000), a reason why uncertainty of this figure is considered to be low. Nutrient emissions from the sewage treatment plant were taken from a recent study which can be considered to be updated with regard to modern sewage treatment technology (SEPA 1997), a ground for why the accuracy in this figure is considered to be high. Emissions of copper were calculated from the use of antifouling products reported by fishermen in the questionnaire and this figure varied considerably between fishermen. Moreover, the type of paint and thereby, content of copper, varied and therefore the value used should be regarded more as an indication of the scale of copper emissions rather than a true value.

5 Conclusions

The present study has shown that fishery is the main contributor to a number of categories of environmental impact in the life cycle of the studied seafood product. Any measures decreasing the use of energy in fishery, will have an impact on the overall environmental performance of the product. Such measures were discussed in a previous study by Ziegler and Hansson (in press). Most important is to fish viable stocks with as high a catch per unit effort (CPUE) as possible, since fishing activity with a low CPUE will lead to high environmental impact per catch. Apart from decreasing fishing effort in different ways, there are two main ways to improve sustainability in fisheries: Modifying fishing practices technically to become more resource-efficient and developing environmentally efficient fisheries for under-utilised species. The first alternative applies to the Baltic cod fishery and could, for example consist of gear modifications, improved engine technology or education of fishermen in fuel-saving vessel operation. Because of the environmental importance of fishery, the most important factor, once the fish is landed, is to use it in an optimal way. The environmental burden occurring because of product loss (e.g. losses in the industry or in the household) has to be added to the product, which is actually used for its purpose, as human food, and therefore, the most important measure after landing to decrease the overall environmental impact of the product can be to decrease product losses.

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